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Variation of diurnal anisotropy during minimum of solar activity cycles 20 and 21

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Abstract : Harmonic analysis technique was employed to study the variation of the amplitude and phase of the diurnal anisotropy during the period 1964–87 including two reversal of total solar magnetic field and three solar minimum 1964–65 ($\mp$), 1976 ($\pm$) and 1986–87 ($\mp$). We observed that during minimum of 1976 ($\pm$) when the north polar magnetic field is positive, the phase of the diurnal anisotropy shifts to earlier hours from the 1800 hrs corotation direction as reported by convection-diffusion model

Keywords : Cosmic ray intensity, Sun-polarity reversal, harmonic analysis technique

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1. Introduction

Anisotropies of galactic cosmic rays (GCR) are studied through the diurnal component, the semi-diurnal component and the deficiency, which often appear along the direction of the interplanetary magnetic field (IMF), in intensity measured by monitors on the spinning Earth. The characteristics of the anisotropies and the level of the isotropic intensity collectively provide a finger-print for identifying modulation processes and the electromagnetic state of the interplanetary space in the neighbourhood of the Earth [1,2].

It is well known that the cosmic ray diurnal anisotropy is caused by the corotation of galactic cosmic ray particles with the magnetic field of the solar system. However, neutron monitor observations indicate that the anisotropy vector exhibits a significant variability in amplitude and phase, when considered on a long-term basis. The studies of Ananth *et al* [3] and references therein related to the long-term behaviour of the diurnal anisotropy, have indicated that the anisotropy consists of two components, one related to the 22-year solar cycle and other related to the 11-year solar activity cycle [4].

The fact that 11-year modulation of cosmic ray intensity is in anti-correlation with the 11-year solar activity cycle is well-established [5,6], although its origin is not fully understood. In addition to this 11-year cycle, there are various features which indicate that a 22-year periodicity in the modulation of cosmic ray intensity is also important [7–11]. The most important feature that seems to have a 22-year periodicity is the diurnal variation [12]

Using the drift theory proposed by Jokipii *et al* [13], it has been suggested that during the solar polar field reversal, the direction of the interplanetary magnetic field is outward above the heliospheric current sheet and the cosmic ray particles enter the inner heliosphere mainly from the polar regions, thus increasing the radial component which leads to an apparent shift in the phase of the diurnal anisotropy vector [14–17].

Ananth *et al* [3] and references therein show that the average diurnal anisotropy vector has been explained as a consequence of the equilibrium established between the radial convection of the cosmic ray particles by solar wind and the inward diffusion of particles along the interplanetary magnetic fields due to radial gradient. Further, a detailed analysis of diurnal anisotropy vector on a long-term basis and on a day to day basis (see ref [3]) clearly indicate that a simple corotational picture derived by the convection-diffusion model is inadequate to understand the diurnal anisotropy characteristics and the systematic shifting of the phase of the diurnal anisotropy to earlier hours for the outward field of the solar magnetic field, which envisages the need of an additional mechanism for explaining the long-term behaviour of diurnal anisotropy.

The purpose of the present work is to compare our observational results of diurnal anisotropy vector which have been studied systematically during the period 1964–87 along with the changing polarity of the solar polar magnetic field on geomagnetic quiet days. The whole span of the analysis also includes solar activity cycles 20 and 21, two reversal and three solar activity minimum of different polarities of the solar magnetic fields.

2. Data analysis

To observe the dependence of the amplitude and phase of the diurnal anisotropy on solar magnetic field polarity, the pressure-corrected hourly data of Deep-River neutron monitor (cut of rigidity R_c = 1.02 GV) is subjected to a simple harmonic analysis technique on each individual quiet day (Five most quiet days in a month are taken into account) for 22-years during the period 1964–87. The yearly average diurnal anisotropy vectors are then obtained by vector averages of the individual days. The average amplitude and phase of the diurnal anisotropy obtained at ground are corrected for geomagnetic effects using the procedure established [18,19] to obtain the anisotropy vector in free space. For an energy independent spectrum ($\beta = 0$), the relative amplitude 0.8448 (in percent) and the phase correction factor for the geomagnetic effects 2.33 (in hours) are used in the analysis.

3. Results and discussion

Figure 1 shows the long-term variation of the amplitude and phase of the diurnal anisotropy vectors along with the polarity of the solar polar magnetic field during the period 1964–87. A cyclic trend of period 22-years in the amplitude and phase of the diurnal anisotropy can be clearly seen from this figure. Further, we note from the figure that during the period when the north polar magnetic field of the sun is positive, the phase of the diurnal anisotropy shifts to earlier hours (1500 ± 1) from the normal corotation direction (1800 ± 1).

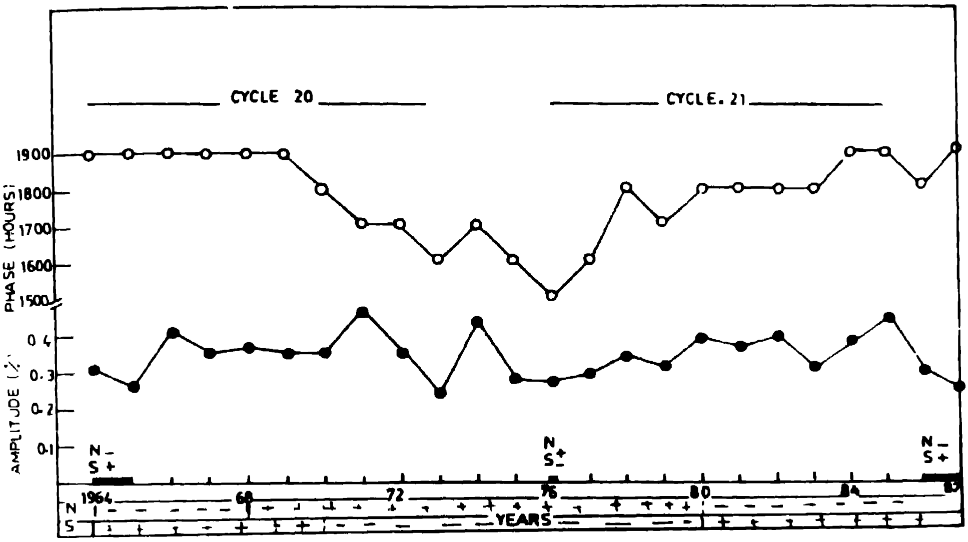

Figure 1. A plot of diurnal anisotropy (Amplitude and Phase) along with the polarity of the solar polar magnetic field during 1964–87

The average diurnal vectors in the interplanetary space over three solar activity minimum periods (see Table 1) of different solar dipole orientations are shown in Figure 2. Figure 2 indicates that during minimum of 1976 (when the north polar magnetic field of the sun is positive), the phase of the diurnal anisotropy shifts to earlier hours (1500 ± 1) as compared to the minimum of 1964–65 (polarity of the north polar magnetic field of the sun is negative) when the phase of the diurnal anisotropy is in 1800 ± 1 hrs corotation direction. Again after 22-years during the minimum of 1986–87 (polarity of the north polar magnetic field of the sun is negative) the diurnal anisotropy phase shifts to back to later hours (1800 + 1) as it was during the minimum of 1964–65 *i.e.* 22-year earlier. This behaviour of the diurnal anisotropy is also visible during the entire period of the analysis (Figure 1).

Our observational results clearly indicate that during solar activity cycles 20 and 21, the phase of the diurnal anisotropy vector is continuously changing (either to earlier hours or towards 1800 ± 1 hrs) for the different solar activity minimum characterized by different polarity of the solar magnetic field *viz.* inward, outward and again inward. This behaviour of the phase or time of maximum of the diurnal anisotropy seen from two different angles indicate that there is a 22-year periodicity in the phase of the diurnal anisotropy which

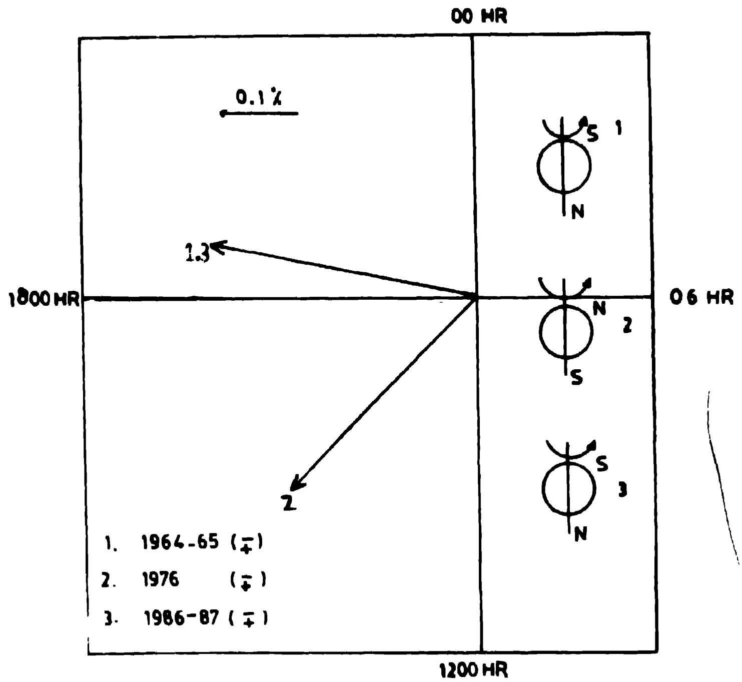

Figure 2. A harmonic dial plot of diurnal anisotropy vector in free space (Amplitude and Phase) over three periods of solar activity minimum of different dipole orientations (on the right is shown the sign of Sun's dipole for these periods)

might be related to the polarity of the solar polar magnetic field. These results corroborate the findings of earlier investigators [16,20–23].

Table 1. Amplitude and phase of the diurnal anisotropy for three different dipole orientations

Period	Polarity of the north pole of the sun	Diurnal vector Amplitude (%)	phase (hrs)
1964-65	∓ inward	0.30	1900
1976	± outward	0.40	1600
1986-87	∓ inward	0.30	1900

The model calculation for high rigidity cosmic rays (~ 50 GV) of Erdos and Kota [14] predicts the change of solar daily vector in 1969. The effect of particle drift in Parker spiral model is such that the predominant access of cosmic rays to the inner solar system is either inward from polar regions (when northern hemispheric polar magnetic field is positive) or inward along helio-equatorial region (when the northern hemispheric polar magnetic field is negative). Erdos and Kota [14], while explaining their theoretical results for high rigidity cosmic rays noted that before 1969 the drift was such that we, on Earth observed galactic particles that had entered the solar system mainly at the helio-equatorial region, while particles had easier access to earth from polar regions after 1969. They conceived that in post 1969 epoch, particles had less chance to experience several encounters with the rotating current sheet and this resulted in less effective corotation.

Our results (see Table 1) obtained for low energy cosmic rays using the neutron monitor data for Deep-River (whose median primary rigidity of response is ≈ 15 GV) are very much in agreement with the theoretical results obtained for high rigidity (≈ 50 GV) particles and can be explained by the drift current sheet model.

The effect of particle drift in the Parker spiral model is such that the magnetic configuration for 1964–65 and 1986–87, when the northern magnetic field was inward, cosmic ray particles have easier access to the inner heliosphere system along the equatorial current sheet and the magnetic field configuration for 1976, when the northern magnetic field was outward, the cosmic rays seen in the inner heliosphere system can primarily form outer boundary near heliospheric pole. In other words, during 1964–65 and 1986–87, protons are expected to flow in along the current sheet and flow out at high latitudes. During 1976, energetic protons are expected to flow into heliosphere at high latitudes and flow out along the current sheet.

4. Conclusions

The conclusions which emerge from the present study are as follows :

1. Amplitude and phase or time of maximum of the diurnal anisotropy vector exhibit a 22-year periodicity which might be related with 22-year solar magnetic cycle.
2. Phase of the diurnal anisotropy shifts to earlier hours from the 1800 hrs corotation direction for the outward field of the sun.
3. Our results and the results of the earlier investigators (Refs. 6–23) indicate that drift is the basic mechanism in galactic cosmic ray modulation which has a natural dependence on the sense of the magnetic field of the sun.

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